U.S. Department of Energy
Office of River Protection
P.O. Box 450
Richland, Washington 99352

0060270

03-TOD-064

SEP 03 2003

Mr. Michael A. Wilson, Program Manager
Nuclear Waste Program
State of Washington
Department of Ecology
1315 W. Fourth Avenue
Kennewick, Washington 99336

RECEIVED
SEP 11 2003
EDMC

Dear Mr. Wilson:

COMPLETION OF HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER (HFFACO) MILESTONE M-48, FINAL REPORT ON ULTRASONIC TEST EQUIPMENT FOR ASSESSING THE LOWER KNUCKLE REGION OF THE DOUBLE-SHELL TANKS (DST)

The HFFACO Milestone Series, M-48-02, requires submission of status reports to the State of Washington Department of Ecology every six (6) months on development, test and eventual deployment of new ultrasonic test equipment to assess the lower knuckle regions of the DSTs. The next report is due by September 30, 2003.

The Final Report for Lower Knuckle Ultrasonic Testing Technology Development – September 2003 (attachment) contains the report on successful deployment of the Tandem Synthetic Aperture Focus Technique (TSAFT) on Tanks 241-AW-102 and AP-101. TSAFT is designed to scan for circumferential cracking, characteristic of stress corrosion cracking in the lower knuckle regions of the DSTs. In addition, the report also describes the use of the extended arm to reach into the air slots near the maximum stress region of the DST using P-Scan technology. These two technologies enable the U.S. Department of Energy, Office of River Protection to adequately assess the material thickness and condition of the lower knuckle region of the DSTs as required by M-48-02. This submittal closes Milestone M-48-02.

If you have any questions , please contact me, or your staff may contact V. L. Callahan, Tank Farms Technical Engineering Division, (509) 373-9880.

Sincerely,

Roy J. Schepens
Manager

TOD:VLC

Attachment

cc: See page 2

SEP 03 2003

cc w/attach:
J. J. Lyon, Ecology
TPA Administrative Record

cc w/o attach:
D. I. Allen, CH2M HILL
E. S. Aromi, CH2M HILL
S. B. Fowler, CH2M HILL
M. N. Jarayssi, CH2M HILL

ATTACHMENT
03-TOD-064

FINAL REPORT FOR LOWER KNUCKLE ULTRASONIC TESTING TECHNOLOGY DEVELOPMENT – SEPTEMBER 2003

13 pages including cover page

FINAL REPORT FOR LOWER KNUCKLE ULTRASONIC TESTING TECHNOLOGY DEVELOPMENT - SEPTEMBER 2003

1.0 INTRODUCTION

Presently, the M-48-02 requirement of the Hanford Federal Facility Agreement and Consent Order between the U.S. Department of Energy (DOE), the State of Washington, Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA) calls for the following activities to be reported to Ecology:

"Develop ultrasonic testing equipment, or an equivalent technology, for assessing material thickness and defects of the predicted maximum stress region of the lower knuckle base metal of double-shell tanks".

Reporting on this technology development started with the March 2001 report and was subsequently reported every six months thereafter. This progress report was to be continued until appropriate equipment was both developed and deployed. This report summarizes the processes, methodology and equipment (i.e., extended arm, and tandem synthetic aperture focusing technique [TSAFT]), that have been developed and successfully deployed for lower knuckle ultrasonic testing (UT) assessment, and is the final technology report required to complete the M-48-02 milestone requirement.

2.0 BACKGROUND

Environmental regulations applicable to the River Protection Project (RPP) require integrity assessment of the double-shell tank (DST) system.[1, 2] By agreement between the U.S. Department of Energy, Office of River Protection (ORP) and Ecology, UT using remotely operated equipment is performed to support integrity assessment of DSTs. UT is used to measure wall thickness and to detect and size pits and cracks. Detection of cracks on the inside surface of the primary tank (i.e., the surface in contact with waste) could indicate the onset of stress-corrosion cracking (SCC). SCC has been determined and/or suspected to be the cause of failure for over 60 of the single-shell tanks (SST)[3] originally used for waste storage, as they were not stress relieved like the new generation DSTs.

Various structural analyses have indicated that the maximum tensile stress on the inside surface of the tank is located at the intersection of the curved lower knuckle and the flat bottom of the tank.[4, 5, 6] As shown in Figure 1 on the following page.

---

1 Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities, 40 CFR 265.191.

2 State of Washington, Department of Ecology Dangerous Waste Regulations, Chapter 173-303, Washington Administrative Code, Section 173-303-640(2).

3 *Characterization of the Corrosion Behavior of the Carbon Steel Liner in Hanford Site Single-Shell Tanks*, WHC-EP-0772, Rev. 0, R. P. Anantatmula, E. B. Schwenk, and M. J. Danielson, June 1994.

4 *A* Comprehensive *Summary of the Analysis of the 241-AW Underground Waste Storage Tanks, Hanford, Washington*, prepared by URS/John A. Blume & Associates, San Francisco, CA for Vitro Engineering, Richland, Washington, July 1981.

5 *Parametric Studies to Support Inspection Criteria for the Hanford Site Double-Shell Waste Storage Tanks*, M. S. Shurrab, M. D. Thomson, J. R. Friley, M. R. Garnich, M. W. Rinker and F. A. Simonen, WHC-EP-0508, 1991.

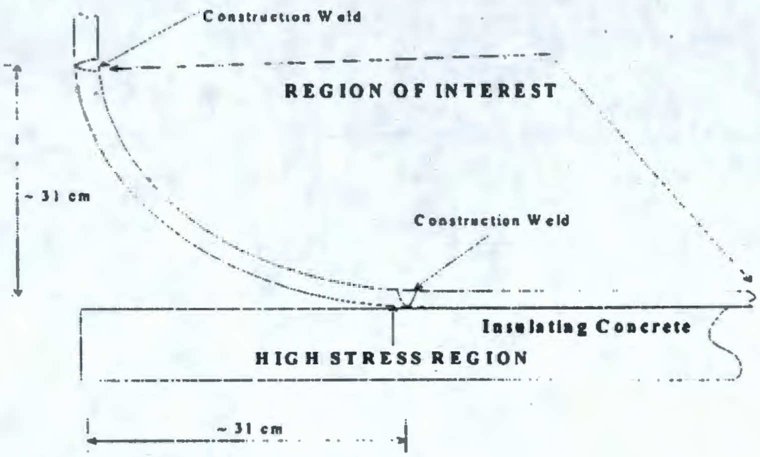


Figure 1 Primary Tank Region of Interest

This stress in the primary knuckle plate is primarily due to bending from gravity loads, which create tensile stress on the inside and compressive stress on the outside surface of the primary tank. SCC from such bending stress would tend to be circumferentially oriented. In addition to bending stress from gravity loads, tensile stress in the horizontal direction (i.e., across a vertical plane through the tank wall) results from hydrostatic loads due to tank waste. This type of stress is commonly referred to as hoop stress. SCC from such hoop stress would tend to be longitudinally oriented (i.e., along a tank meridian). For design loading conditions, previous stress analyses indicate the location of maximum hoop stress is in the upper portion of the lower knuckle region, or the lower part of the vertical tank wall.[7] The loading conditions considered in these structural analyses include various combinations of dead weight of the tank structure, soil overburden, uniform live load, concentrated live load, hydrostatic loads, seismically induced loads, and thermal loads due to waste temperature.

The highest stress area, and the area believed to be the most susceptible to stress corrosion cracking is located at the interface where the tank knuckle meets the concrete pad underneath the tank. The idea of conducting the inspection from the inside of the primary tank is not viable since the tank is full of highly radioactive waste and condensed solids (e.g., sludge or saltcake) and cannot be effectively emptied or cleaned. Therefore, the inspection must take place on the outside of the primary tank in the annulus region.

---

[6] *Accelerated Safety Analyses, Structural Analyses Phase III, Double-Shell Waste Storage Tank Evaluations of the Dome, Haunch, Wall and Footing*, WHC-SD-WM-SARR-40 (draft), 1996.
[7] Ibid.

FINAL REPORT FOR LOWER KNUCKLE ULTRASONIC TESTING TECHNOLOGY DEVELOPMENT - SEPTEMBER 2003

Hanford Federal Facility Agreement and Consent Order milestone M-48-02[8] required (until equipment had been deployed) biannual submittals of status reports on development of "ultrasonic testing equipment, or an equivalent technology, for assessing material thickness and defects of the predicted maximum stress region of the lower knuckle base metal of double-shell tanks."

Previous submitted status reports identified two UT technologies selected for deployment, which in combination satisfied the inspection requirement:

- Deployment of an Extended Arm on an existing wall crawler
- TSAFT imaging technology

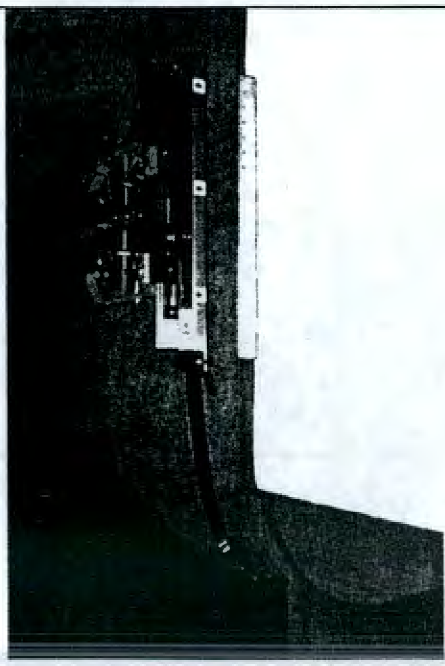
3.0 TECHNOLOGY EVALUATION

This section provides results of evaluation of capabilities and limitations of the two technologies noted in Section 2.0, and describe the strategy and present results for examining the high-stress region of the lower knuckle, utilizing these two specialized UT devices in combination.

3.1 Extended Arm Development

The extended arm adaptation to the normally used P-scan UT system (hereafter referred to as "Extended Arm") was successfully first deployed in DST 241-AW-102 in July 2002. The Extended Arm equipment is shown in the photograph of Figure 2 below.

Figure 2 P-Scan Ultrasonic Tester and Transducer Extension Arm



[8] Hanford Federal Facility Agreement and Consent Order Change Control Form, Change Number M-48-01-01, October 30, 2001.

The Extended Arm (sometimes referred to as the "Y-Arm") reaches downward and examines a larger arc length of the lower knuckle, within the accessible regions of the DST annulus. However, the arc length that is examined is limited by interference of the UT transducer assembly with the bottom insulating concrete pad separating the primary tank and secondary liner. The Extended Arm reaches down onto and scans the upper portion of the lower knuckle for flaws and thickness. The Extended Arm can also utilize the air circulation slots cut into the insulating concrete pad to reach down to the tangent region of the lower knuckle, and measure plate thickness. Projection of the extended arm into the air slots is attempted for each examination of the knuckle region, to provide as much overlap as possible between the Extended Arm measurements and the TSAFT measurements in the knuckle area. The Extended Arm P-scan arrangement has good sensitivity to detect and size pits and cracks, and readily measures wall thickness.

3.2 Tandem Synthetic Aperture Focusing Technique (TSAFT) Imaging Technology

The Synthetic Aperture Focusing Technique (SAFT) is an ultrasonic testing imaging method developed to allow UT examination with reasonably sized inspection equipment that is the equivalent of widely spaced UT generators (i.e., large physical apertures). "Synthetic Aperture Focusing" refers to a process in which the focal properties of a large aperture focused transducer are synthetically generated from UT data collected over a large area using a small transducer with a divergent sound field[9]. The processing required to focus this collection of data has been called beam-forming, coherent summation, or synthetic aperture processing. The resultant image is a full-volume, high resolution, and high signal to noise ratio, focused characterization of the inspected area.

Using a single ultrasonic transducer in a pulse-echo configuration or a pair of transducers in a pitch-catch mode, SAFT works well for detection and location of planar type discontinuities, but may provide ambiguous results for defect sizing at distances necessary to perform the knuckle examination. However, utilizing an advanced ultrasonic inspection technique called Tandem SAFT or TSAFT, [10] sizing of defects at great distances from the transducers can be accomplished.

Fundamentally, the TSAFT configuration provides a uniform illumination of the vertical object plane. At the completion of each pass of the transmitter and receiver, the two-transducer TSAFT configuration is incremented so that a rectilinear pattern is obtained and the vertical extent of a defect can be accurately measured. Sizing is accomplished by measuring the extent of the UT images from the two transducers in the TSAFT mode. Both transducers are scanned equal distances but in opposite directions as shown in the drawing of Figure 3, on the next page. Note that the crack defect in the plate is shown by the small white line discontinuity.

---

[9] Hall, T. E., L. D. Reid, and S. R. Doctor. 1988. The SAFT-UT Real-Time Inspection System - Operational Principles and Implementation, NUREG/CR-5075. U.S. Nuclear Regulatory Commission, Washington, D.C.

[10] Doctor, S. R., G. J. Schuster, L. D. Reid, and T.E. Hall. 1996. Real-Time 3-D SAFT-UT System Evaluation and Validation, NUREG/CR-6344. U.S. Nuclear Regulatory Commission, Washington, D.C.

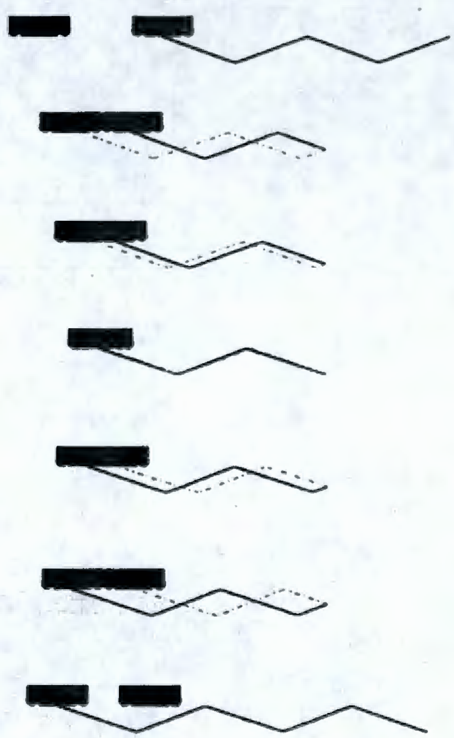


Figure 3 TSAFT Side View Showing V Paths

Figure 3 provides a graphical representation of the UT signal "painting" (insonification) of the entire crack face from the corner-trap signal to loss of signal. Of the three technologies evaluated and reported in the March 2001[11] status report, only the TSAFT imaging technology had the potential to examine the area of the lower knuckle at its intersection with the flat tank bottom along a 20-foot circumference of the tank, as required by Hanford Federal Facility Agreement and Consent Order milestone M-48-02.

During fiscal year (FY) 2000, laboratory testing on a mockup test plate demonstrated TSAFT could be effective in detecting and sizing circumferentially-oriented flaws in the knuckle region and beyond.[12] In FY 2001, development work was authorized to develop a prototype remotely operated UT inspection system utilizing the TSAFT imaging technology with the plan of

---

[11] Letter from James E. Rasmussen, U.S. Department of Energy, Office of River Protection, to Michael A. Wilson, State of Washington Department of Ecology, *Submittal of X-032-20B-T02, "Submit to Ecology the Ultrasonic Testing Equipment Development,"* 01-OPD-031, March 30, 2001.

[12] *Evaluation of SAFT/TSAFT Technology for the Inspection of Hanford's Double-Shell Waste Tank Knuckle Regions*, PNNL-13321, A. F. Pardini, A. A. Diaz, September 2000.

demonstrating the capability of the technology on a DST in late FY 2002. In FY 2002 the prototype TSAFT and its robotic crawler was developed and acceptance testing completed in May 2002. Operator training and qualification started at the end of August 2002, and completed in September 2002. The first field deployment in DST 241-AW-102 was successfully completed in February 2003. Figure 4 is a photograph of the TSAFT equipment on a DST mockup.

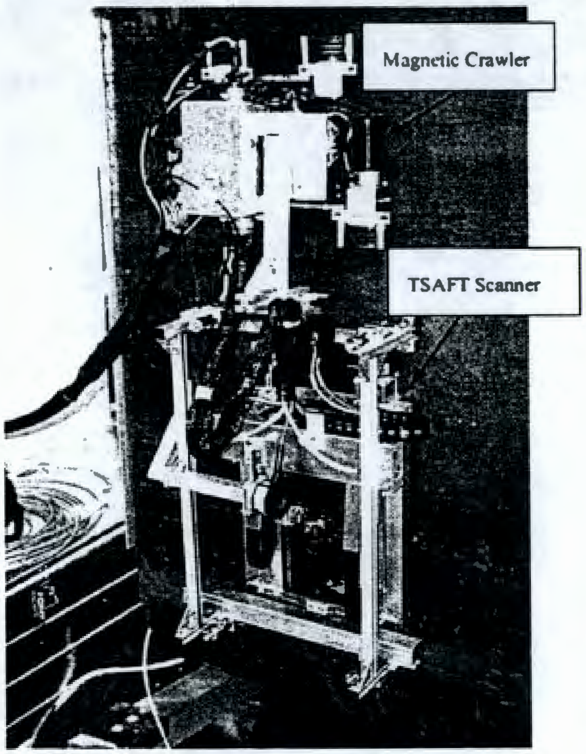


Figure 4 TSAFT Scanner on Mockup

Figure 5 Sound Propagation in Knuckle Region

Early in the development stages, it was decided to concentrate on developing the ultrasonic technology rather than exhausting funds on the deployment platform. Therefore, the program utilized an inexpensive commercial off-the-shelf magnetic wheel crawler to deliver the TSAFT scanning bridge to the knuckle region. It also became apparent that to place the transducers on the actual knuckle was difficult and would require an extensive design effort. In order to achieve program goals in the desired time frame, the system was designed to scan from above the upper knuckle weld. Sound propagates down around the knuckle and under the tank. In this configuration shown in Figure 5 (above), sound propagates through the upper knuckle weld, continues throughout the knuckle, through the lower knuckle weld, and under the tank. To validate the effectiveness of crack detection by TSAFT, a variety of cracks were introduced into a knuckle mockup (saw cuts, spark machined, and actual SCC induced cracks) and then scanned by the TSAFT equipment. This crack detection methodology was also used to train and qualify the Hanford Tank Farm operator, who did not have knowledge of the crack locations and sizes, and needed to find and size them to qualify in the equipment operation. An actual TSAFT scan of one such mockup plate with a drawing of the plate defects is shown as Figure 6 on the following page.

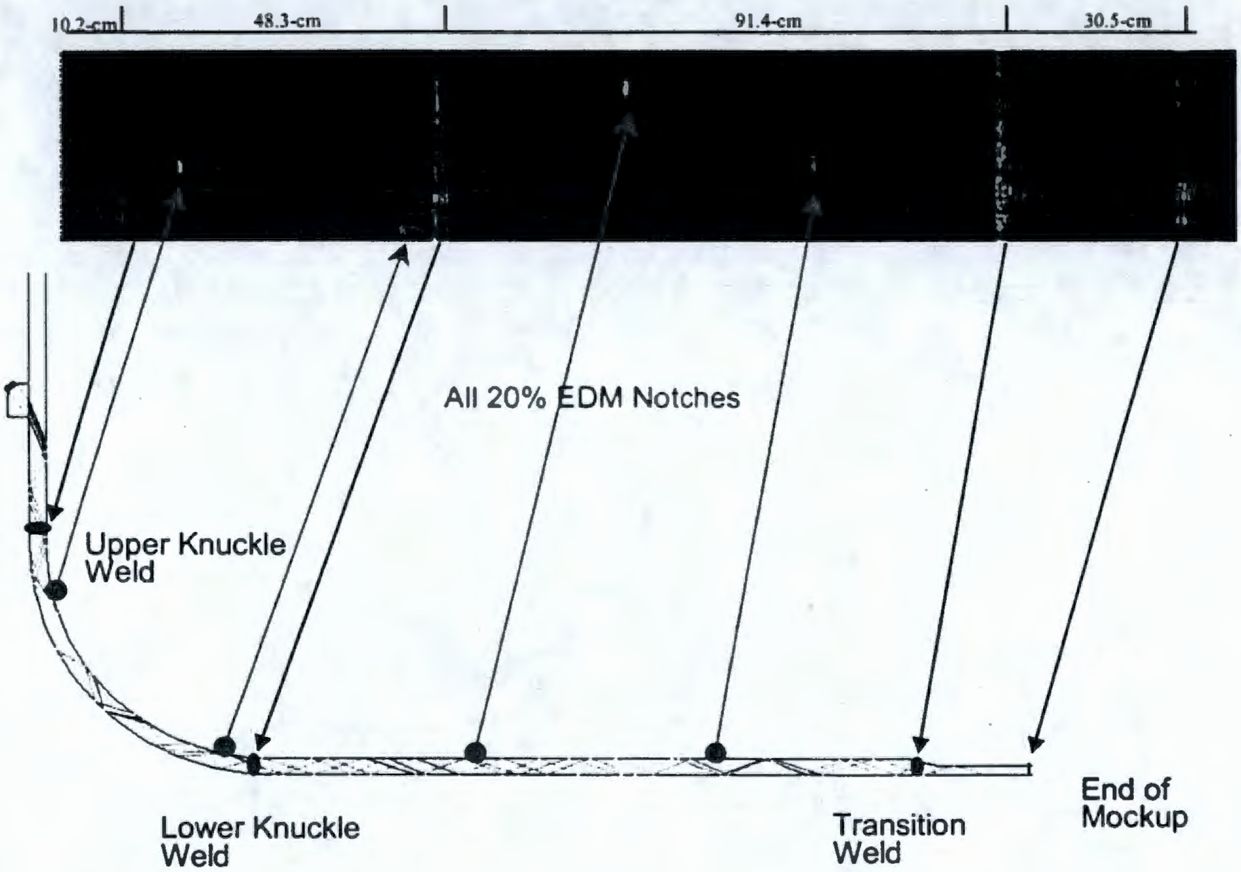


Figure 6 Plan View (C-Scan) of Entire Knuckle Mockup – All notched defects at 20percent of Plate Wall Thickness

The TSAFT has high sensitivity for detecting cracks with a circumferential orientation, but lacks sensitivity for cracking in other orientations, and for accurate sizing of cracks below 0.15 inches. Also, testing to date has indicated that the TSAFT system as currently configured will not be capable of measuring wall thickness or provide pit detection or sizing capability. Therefore the strategy that combines the capabilities of both the Extended Arm and the TSAFT was pursued to complete DST lower knuckle inspections, as described in Section 3.3 below.

3.3 Comprehensive Strategy for Lower Knuckle Ultrasonic Examination

The Extended Arm provides UT measurements for both flaw detection and plate thickness measurement of the knuckle from its upper weld to the vertical tank wall to just above or adjacent to the high stress region, using the air lots, as feasible, to overcome the physical interference with the concrete pad that supports the primary tank bottom and separates it from the secondary liner. The TSAFT equipment, on the other hand, projects its special UT signal from the upper knuckle weld through the knuckle plate metal, around to the bottom knuckle weld (where the knuckle joins the bottom plate), and provides for UT detection and measurement of potential SCC in the lower knuckle, but does not measure plate thickness. The overlapping Extended Arm examination of the knuckle above and adjacent to the high stress region allows for plate thickness measurement, as well as flaw detection to compare with the TSAFT results in the same regions, and by minimal extrapolation to assess the thickness expected in the high stress region.

Thus the Extended Arm is being used to detect wall thinning, pitting, and cracking in the lower knuckle region, and the TSAFT is being used to supplement the Extended Arm to detect and size circumferentially-oriented cracks in regions of the knuckle that are inaccessible with the Extended Arm. Therefore, the combination of the Extended Arm capability to measure pitting and wall thickness down to the highest stress region and the TSAFT crack detection capability in the high stress region fulfills the M-48-02 requirement for "...assessing material thickness and defects of the predicted maximum stress region of the lower knuckle base metal of double-shell tanks."

4.0 EQUIPMENT VENDORS AND DEVELOPERS

The Extended Arm was provided by FORCE Institute of Denmark, through Swain Distribution Inc., located in Searcy, Arkansas, its U.S. supplier. Testing and qualification of the system was conducted by COGEMA Engineering Corp., Richland, Washington, with support and oversight by the Pacific Northwest National Laboratory (PNNL) Non Destructive Examination (NDE) Measurement Systems Group, Richland, Washington.

TSAFT was developed, tested, and demonstrated by PNNL, Richland, Washington. PNNL has been working to develop and enhance this technology for the past 10 years for the Nuclear Regulatory Commission and the Department of Energy. PNNL executed a development strategy that focused on utilizing off-the shelf crawler technology and computer hardware and integrating it with their specialized software and transducer motion control hardware.

5.0 DATA QUALITY

Data quality requirements are expressed in terms of accuracy as follows:

Wall thinning	± 0.02 inches
Pit dimensions	± 0.05 inches
Crack depth[13]	± 0.10 inches

The accuracy values above are the same that have been used for qualifying equipment, procedures, and personnel in the ultrasonic vertical wall examinations of DSTs performed to-date, as originally cited in the tank examination report for tank 241-AN-107.[14]

[13] TSAFT was only qualified for crack depth sensitivity since TSAFT physics do not permit measurement of pits and wall thinning. The Extended Arm T & P-scan was qualified to all three Data Quality Requirements.

6.0 OPERATOR QUALIFICATION

Operator Qualifications require:

- Ultrasonic examination system operators and analysts shall be qualified and certified to at least level II in accordance with the American Society for Nondestructive Testing (ASNT) recommended practice SNT-TC-1A.

- Ultrasonic examination reports shall be reviewed and accepted by a level III in accordance with the ASNT recommended practice SNT-TC-1A.

- Ultrasonic examination system operators and analysts using lower knuckle ultrasonic examination equipment shall have 40 hours of advanced detection and sizing training applicable to that equipment.

The TSAFT prototype was developed and the acceptance testing was completed in May 2002 (PNNL Acceptance Test Plan and Procedure, dated May 2002[15]). PNNL designed the Performance Demonstration Test (PDT) to qualify the COGEMA Engineering Level III certified inspector (W. H. Nelson), in the operation of the TSAFT system. The PDT utilized a series of knuckle mockups and test plates containing various sizes and depths of anomalies and cracks, including intergranular stress corrosion cracks. Operator performance was tested in four areas: calibration, detection, location and defect sizing. The PDT was a blind test, with only the examiner knowing the characteristics of the anomalies in the plates. The operator (Mr. Nelson) successfully completed all phases of the PDT in September 2002 (PNNL Report, dated November 14, 2002[16]).

---

[14] *Final Results of Double-Shell Tank 241-AN-107 Ultrasonic Inspection*, HNF-3353, Rev. 1, C. E. Jensen, September 1999.

[15] *Remotely Operated Nondestructive Examination System, Acceptance Test Plan and Procedures*, RONDE-40924-ATP, A. F. Pardini and T. J. Samual, May 2002.

[16] *Ultrasonic Inspection Results for Double-Shell Tank 241-AW-102*, RPP-11581, Rev. 1, C. E. Jensen, February 2003, Attachment 3.

FINAL REPORT FOR LOWER KNUCKLE ULTRASONIC TESTING TECHNOLOGY DEVELOPMENT - SEPTEMBER 2003

7.0 FIELD DEPLOYMENT

Extended Arm and TSAFT Examinations have been completed for the knuckle regions of DSTs 241-AW-102 (report RPP-11581), and 241-AP-101 (report RPP-13546). Work on the DST AZ-102 knuckle is in process and is expected to complete by the end of August 2003. The Extended Arm examinations are done as per the Figure 7 drawing. An approximately 21-ft circumferential section of the knuckle is examined. Also, the Extended Arm is lined up with at least four of the insulating concrete air slots to allow the arm to extend to approximately the lower knuckle tangent point, to overlap the following TSAFT examination as much as possible, and to obtain plate thickness in these regions. Each band in the Figure 7 sketch represents one ft of the knuckle section examined by the Extended Arm for pitting, thinning and cracking defects.

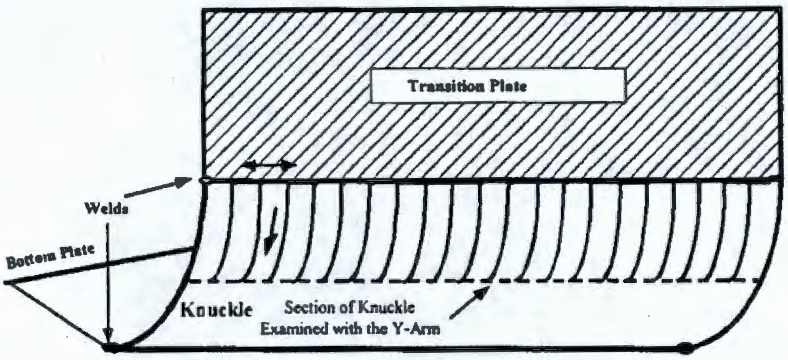


Figure 7 Sketch of Knuckle Region UT Examined by the Extended Arm ("Y-Arm")

With the Extended Arm transducer positioned 3 inches below the Plate #5 to knuckle weld, the scanning bridge was set to scan the transducer downward an additional distance of approximately 12 inches in 0.03 inch steps. Upon completion of the scan, the Extended Arm bridge was indexed circumferentially 0.04 inch and the scan downward is repeated to obtain a pixel size 0.03 x 0.04 inch. Thus the scanned area of the knuckle is approximately 12 inch by 21 feetF.

Additional Extended Arm scanning, for plate thickness only, is done on four areas that were accessible in the air slots that extend under the tank in the concrete support foundation. Figure 8 provides an end view (looking down the air slot), and Figure 9 provides a side view (looking along the circumference of the tank) of the examination of the lower knuckle in the region of the air slots.

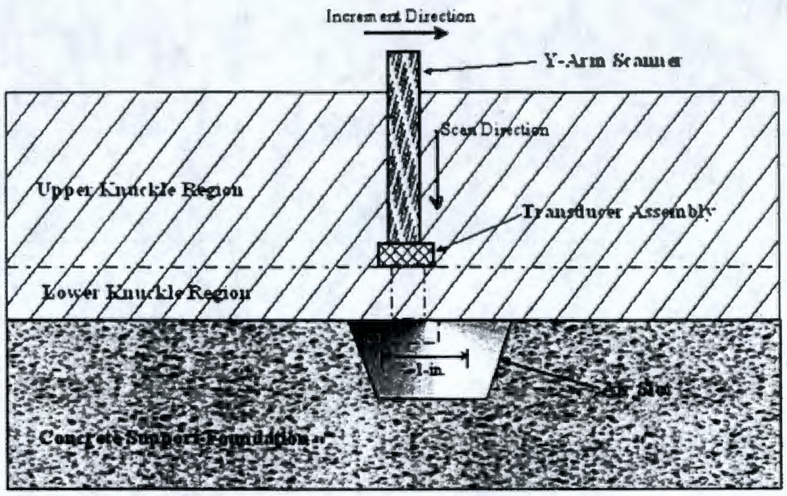


Figure 8 Lower Knuckle Examination in Air Slot Regions (End View)

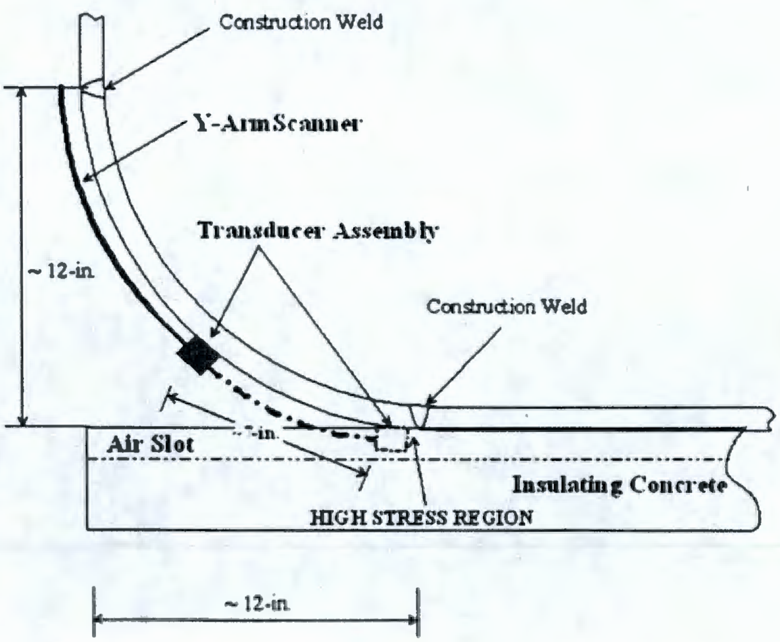


Figure 9 Lower Knuckle Examinations in Air Slot Regions (Side View)

For the knuckle regions of DSTs 241-AW-102 and 241-AP-101, there were no areas that exceeded the wall thinning reportable level of 10 percent of the nominal thickness. No reportable pitting or circumferentially oriented crack-like indications were detected in the portions of the knuckle area examined by the Extended Arm.

The same knuckle sector as examined by the Extended Arm was then examined with the TSAFT equipment. The examination consisted of 25 individual scans, each being 12.5 inch width (circumferential direction). The TSAFT crawler was moved around the circumference in 10-inch increments, thereby providing for a 2.5-inch overlap during data acquisition. The total amount of knuckle scanned was approximately 250 inch measured circumferentially around the tank. The data was displayed in a C-scan (plan) view (see Figure 6) and provided an image of the entire knuckle, from upper knuckle weld to lower knuckle weld, inclusive of the predicted high-stress region. The examination of Tanks 241-AW-102 and 241-AP-101 indicated no circumferential crack-like indications were present in the approximately 21 circumferential feet scanned of the knuckle region.

8.0 SUMMARY

The TSAFT equipment developed and deployed has a high sensitivity for cracks with a circumferential orientation, but the TSAFT system as currently configured is not capable of measuring wall thickness or providing pit detection. The TSAFT equipment, projects its special UT signal from the upper knuckle weld through the knuckle plate metal, around to the bottom knuckle weld (where the knuckle joins the bottom plate), and provides for UT detection and measurement (sizing) of potential SCC in the lower knuckle.

The Extended Arm provides UT measurements for both flaw detection (pitting and cracking) of the upper portion of the knuckle, and plate thickness measurement of the knuckle down to the high stress region, using selected air slots.

The overlapping Extended Arm examination of the knuckle above and adjacent to the high stress region allows for plate thickness measurement, as well as flaw detection to compare with the TSAFT results in the same region.

Thus, this summary final technology report validates that CH2M HILL Hanford Group, Inc. (CH2M HILL) has successfully developed and deployed the specialized UT inspection equipment for assessment of the DST bottom knuckle region. CH2M HILL has demonstrated that the combination of the capabilities of the two selected technologies satisfies the M-48-02 requirement for assessing material thickness and defects of the predicted maximum stress region of the lower knuckle base metal of double-shell tanks.